Meet TED, The Army's Computerized Tank Mechanic

"If You're Going to Stay in a Comfort Zone, Then You're Not Going to Field the System"

COLLIE J. JOHNSON

If your circle of friends includes Army tank mechanics, no doubt you've heard of the new guy on the block-TED. And no doubt, TED is already or will soon be making your life much easier. Just who, or more appropriately what is TED? The Turbine Engine Diagnostics System or TED, developed by the Army Research Laboratory at Aberdeen Proving Ground, Md., is already paving the way for soldiers to toss their technical manuals (TM) and trust TED. In an Army that still routinely hands out 1,000-page TMs to its tank mechanics, TED is a passport to the information age; as one soldier put it, "TED is my buddy."

A typical TED demo to a class of tank mechanics observing the software perform for the first time, generates an enthusiasm and type of "word of mouth" advertisement that money can't buy. Typically these soldiers want to know where they can get TED, how, and how soon. The class instructor, Army Staff Sgt. Eddie Smith fires up an actual M1 tank engine and ensures they not only observe, but actually get into the system to troubleshoot and diagnose. They learn that a health maintenance check of the engine, which was a manual process that lasted two to three hours and required two mechanics, could now be done by TED in about 10 minutes (half of which is warm up time for the engine). That gets their attention.

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Army's M1 Tank Mechanics T

Photos courtesy Army Research Laboratory

cs Toss Their TMs & Trust TED

TED not only helps tank mechanics diagnose system faults, but can also order required spare parts, provide step-by-step instructions on how to perform required repairs, perform tests to ensure that the repairs correct the problem, maintain necessary maintenance records and associated forms, and provide a comprehensive online tutorial on AGT-1500 turbine engine maintenance procedures. TED also features online tutorials on *Microsoft Windows*, the Ground-Hop Support Set (GHSS), Automated Breakout Box (ABOB) and the Digital Multimeter.

More good news—the TED software is *Windows*-compliant and will run on any 486 computer with 8 Megs of RAM, a 500 Meg hard drive, a Super VGA monitor, and a mouse. TED will also run on any touch screen-compatible computer and functions well on a desktop as well as a laptop.

As of January 1997, there were 65 Army National Guard units using TED and ABOB. Fielding to active Army and Marine units is expected to begin in spring 1997, with a goal of 200 copies of TED and ABOB to all maintenance support units with M1 tanks.

The TED package being fielded to Army maintenance units includes both hardware and software. The hardware, called ABOB (Automated Breakout Box), consists of a standard issue BOB (Breakout Box) with circuits added to select one of the 128 channels and convert the analog signal to digital before passing it to the computer. The TED software is issued on CD and replaces the 7-foot stack of manuals for the M1 engine.

PM Abrams has officially recognized the hardware and software, designating the TED CD as TM 9-2500-511-34&P, and assigning NSN 5999-01-436-8900 to the ABOB.

Why the Need?

By August 1991, several factors were contributing to the selection of tank maintenance as an appropriate domain for further development and research into expert diagnostics systems. First, it became apparent that the Army Ordnance Corps was going through a dramatic reduction in force, a large component of which was the loss of aggregate years of master diagnostician expertise in turbine engine diagnostics and repair. This realization, coupled with the rising cost to maintain the Abrams AGT-1500 gas turbine engine, caused the Ordnance School Directorate of Combat Developments to consider various options to improve turbine engine diagnostics. One of the options discussed was the development of an expert system that would capture those diagnostic heuristics (or rules of thumb) that are often lost as master diagnosticians retire or leave the service. In addition, TED was to be easy to use and must allow a novice mechanic the capability to perform his or her duties as well as a master diagnostician.

A second reason for choosing tank maintenance dealt with a new Army

"TED has been cited as a project that exemplifies three key elements of our Defense Science and Technology Strategy: the ubiquity and importance of information technologies, the need for greater attention to affordability, and the priority on accelerated transition to operational use. As evidenced by the rapid acceptance and appreciation of TED's capabilities by Army personnel, this system is a clear example of the successful transition of artificial intelligence (AI) technology to the operations and maintenance aspects of military systems, with a resulting decrease in costs and an increase in readiness.

I would like to point out that the tutorial system, Diagnostic Intelligent Tutoring System (DITS), which complements TED as a diagnostic trainer, was initially funded by the U.S. Army AI Center. As part of the DoD Science and Technology (S&T) program, this AI Center has been instrumental in the development, promotion, and transition of AI technology within the Department.

Artificial intelligence technology will continue to be funded and developed within the DoD S&T program, with increasing emphasis on transition to operational use. I anticipate that we will have many more examples—of which TED is an outstanding one—of the practical utility of this technology in the not-too-distant future."

— Anita K. Jones
Director, Defense Research & Engineering
January 2, 1997

funding directive called Stock Funding of Depot Level Repairables (SFDLR). If you were a company commander in the past, and one of your tanks broke down, it was fixed for free (as far as you, the commander, were concerned). Today, as that same commander, you are billed for your maintenance costs. The hope of the new doctrine is that it will reduce overall maintenance costs, without adversely affecting unit readiness. Fortunately, the Army realized that SFDLR alone, without better maintenance aids for the mechanic, was not the final answer to reducing high maintenance costs. Hence, TED was developed to provide the mechanic with a computer program that enables apprentice mechanics to perform like master mechanics, thereby increasing diagnostic efficiency without a substantial investment in new test equipment or increased training costs.

The third reason for choosing a tank maintenance domain was a revision to current Army maintenance doctrine. Under the new doctrine, when an engine fails it is pulled from the tank and sent to Direct Support (DS). The tank hull remains at the unit, a new engine is sent forward, and the tank is quickly returned to full operational status. The defective engine is then analyzed at DS and if repairs can be made at DS, it is returned to standby status for use in another tank. However, if repairs include depot-level tasks, the engine must be evacuated. The U.S. Army Tank-Automotive Command realized that a large portion of the AGT-1500 depot-level repairs could be performed at DS level. TACOM initiated a program to authorize many of these maintenance tasks at DS level. That program is referred to as DS (+). TED provided the platform from which depot-level maintenance expertise (most of which was civilian and contractor-based), could be readily communicated to DS mechanics in an understandable and easy-to-use format. The adoption of DS(+) will markedly improve Abrams readiness rates.

The Real Work Begins

Responding to the Army's need for a light-weight, visual expert system that will provide the best diagnostic procedures available for the Army's M1 AGT-1500 turbine engine, the U.S. Army Ordnance Center and School took the lead. In August 1991, they put together a team of computer scientists from Army Research Laboratory (ARL); subject matter experts (SME) from the Army Ordnance Center and School (USAOC&S); contractor personnel from Textron-Lycoming; systems analysts from Strategic Logistics Agency (now referred to as Logistics Integration Agency); training specialists; and cognitive psychologists from Applied Science Associates. Under the direction of program manager, Army Lt. Col. Orlando Illi, Jr., this team of diversified specialists began what has become the first artificial intelligence project to be funded, monitored, and fielded by the Army.

Early into the TED project, the TED program manager chartered a study panel to establish specific design goals for TED functionality. This group consisted of Textron-Lycoming (the AGT-1500 prime contractor) engineers; Ordnance School SMEs from the Directorate of Combat Developments and the Directorate of Training; Ordnance School turbine engine maintenance instructors and their students (AIT, NCO, and warrant officer); and ARL computer scientists. After the study was completed, the TED team developed the following three design goals: capable of supporting multiple levels of expertise on each screen, which would enable an apprentice AIT graduate mechanic to use TED and function at the same level as a master diagnostician; as easy to use as a video game; and flexible enough to allow for rapid prototyping.

First and foremost, TED software needed to perform basic diagnostics and produce results that routinely would meet or exceed the accuracy expected of the most experienced mechanic. It needed to enable an AIT graduate to perform his or her duties at a master diagnostician level, which would allow TED to exhibit an overall effectiveness that would be significantly better than the system it is replacing. Otherwise, it will lose soldier respect, and it will not be used.

Soldiers will always ask the most experienced mechanic why something does not work. These master diagnosticians have a sixth sense and "know" what is wrong with the engine. It was the TED team's desire to have that "sixth sense" built into TED so that novice and apprentice mechanics could benefit from years of aggregate expertise. The problem was how best to design an expert system that would not bore the expert and baffle the beginner, but still enable both to benefit and to increase their efficiency.

Given the requirement to make TED useful for all three categories of mechanics, the TED team decided to design the main screen at the expert level. This would allow each screen to provide three levels of expertise: expert, novice, and apprentice. Experts need little or no help from TED. Novice mechanics (recent AIT Graduates) require extensive step-by-step instructions, while apprentice mechanics (those with more then one year of experience after AIT) need a system that enables them to ask for additional information. Once the main diagnostic screen is accessed, the soldier can control the level of interaction through the use of HOW, WHY, HELP, and TOOLS buttons for each task performed The HOW button gives the user more help, in the form of additional text and graphical images, and will automatically drop the user into a lower skill level (as described in the preceding paragraph). The WHY button gives the user a global picture: why the test is performed, and why he or she is being asked certain questions.

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In addition, it informs the user of the current goals of the system. All WHY information is presented in a text window. The HELP button provides the user with helpful hints for performing a specific task. The TOOLS button displays all required tools and special test equipment. In addition, TED's online tutorial provides a comprehensive review of turbine engine maintenance procedures for all levels of expertise. As TED is used, mechanics' skill levels improve, and they require less help from TED.

"Initially we thought that was going to be overkill," said Illi, "but it wasn't. We were looking at it from a technical standpoint of, 'Yes, I know and understand the system I'm looking at.' But you've got to remember who the ultimate user will be. I guess what we learned is it was always going back to the 19-year-old that graduates from Aberdeen Proving Ground as a 63 Echo. And as long as we focused on the solder, it became easy for us."

Second, TED had to be easy to use, or otherwise it will sit on the shelf. Mechanics have favorite stories of diagnostic equipment that does nothing but occupy lots of storage space. The TED team targeted the current generation X soldier who has been raised on video games. TED software was designed in that vein, making it easy and fun to use. Each screen had the same format, with color photos and pop-up windows. All the soldier was required to do was point and click with a mouse or a touch-screen computer.

Third, it must be flexible enough to allow for insertion of updated modules without affecting the entire logic structure. This feature was extremely important in that the TED team routinely incorporated recommended changes gleaned from basic and advanced NCO course students, who were shown new modules as they were developed. "Once the students commented on the applicability of the module," said Illi, "changes were incorporated—often as the soldiers looked on. It was a powerful tool that enabled us to incorporate those ideas and changes that the soldier wanted rapidly, without having to completely rework the entire system."

About the Software

The main diagnostic software in TED is a *Windows*-based shell called *Visual Expert* from SOFTSELL™. *Visual Expert* is based on a procedural reasoning paradigm called Procedural Reasoning System (PRS).[1,2] PRS is a visual method of encoding reasoning strategies used by expert problem solvers. The knowledge is represented graphically with semantics suited to the procedural, goal-oriented style of problem solving, and PRS is best suited for problems that are both procedural and goal oriented, e.g., diagnostics, including triage or deciding what problem to fix first.

A procedural approach uses an ordered, step-by-step prescription to obtain a desired result, possibly including alternate paths in case of failure. Such an approach is also goal oriented if some steps are goals to be achieved rather than specific actions to be performed.[3] Army TMs closely follow this paradigm. They are often graphical in nature with decision trees displayed on the page. Some nodes represent goals to be achieved; others represent specific tasks to be performed.

From TED's main menu screen, the mechanic is given access to the entire TED system. As shown in Figure 1, TED separates this access into three main modules and two special applications. The first main module, entitled TED, directs the mechanic to the bulk of the diagnostic and maintenance expertise. The second main module, Automated Breakout Box (ABOB), allows the automatic interrogation of the signals from the engine. In the final main module, Repair Parts and Special Tools List (RPSTL), is found the automation of the repair parts and special tools system. Under the two special applications are the Diagnostic Intelligent Tutoring System (DITS) and special system administration functions.

First Main Module—TED

The main TED module separates the troubleshooting and maintenance routines into three specific areas:

- Inspections
- Operational Checks
- Maintenance Procedures

Inspections. The inspections module guides mechanics through a series of detailed inspections of the engine to determine its current operational state and to verify recorded faults and identify new faults. The engine is divided into separate inspection stations, and at each station the routines guide the mechanics through a 100-percent inspection of that region. Upon completion, an electronic DA Form 2404 with noted deficiencies is automatically generated. When deficiencies are noted, TED automatically links to pertinent sections of maintenance and repair parts modules.

Operational Checks. The second area under the TED module is the operational checks. The operational checks organize DS diagnostic logic by terms easily recognized by mechanics, regardless of experience. Troubleshooting areas include: No Start, Protective Modes, Low Power, High Oil/Smoke, Metal Generation, Quick Coast Down, Unscheduled Shutdown, Rapid Functional Assessment, Compressor Surge, Leak Checks, Pre-Operational Checks, and Operational Checks. Each of the 12 submodules contains diagnostic logic to first determine the cause of the faulty symptom, and once the cause has been detected, to link the appropriate maintenance and repair parts modules.

Maintenance Procedures. Maintenance actions for any component include adjust, repair, remove, and replace. The procedures can be invoked in either browse mode or data-driven mode. When in browse mode, maintenance procedures are manually selected through menus and submenus. This provides experienced mechanics the flexibility of viewing only the procedures that they need, while bypassing familiar or routine tasks. When in the data-driven mode, TED automatically establishes the correct links to all pertinent maintenance procedures and to sections of the repair parts manual.

Second Main Module—ABOB

The ABOB main module provides the mechanic an interface to the ABOB. Conceived and developed by Dr. Mark Kregel from ARL, the ABOB is an automated version of the Breakout Box (BOB), which is a diagnostic tool that is now in the field. Currently, mechanics must manually connect the BOB to the AGT-1500 electronic control unit. Once connected, mechanics must then manually read voltages and then manually calculate whether the readings represent a problem. This process is fraught with errors and is time consuming.

The ABOB automates the entire process because it is capable of reading 128 channels of data simultaneously. These signals are passed to TED through a standard serial port. ABOB can be used with or without TED to display voltages on the computer screen in either numerical or graphical format. The ABOB software automates the manual tasks associated with the BOB by providing instantaneous access to all of the engine's voltage signals. When TED is run with ABOB, signals can be automatically monitored, and when a fault occurs, mechanics will be notified of the problem within seconds instead of minutes.

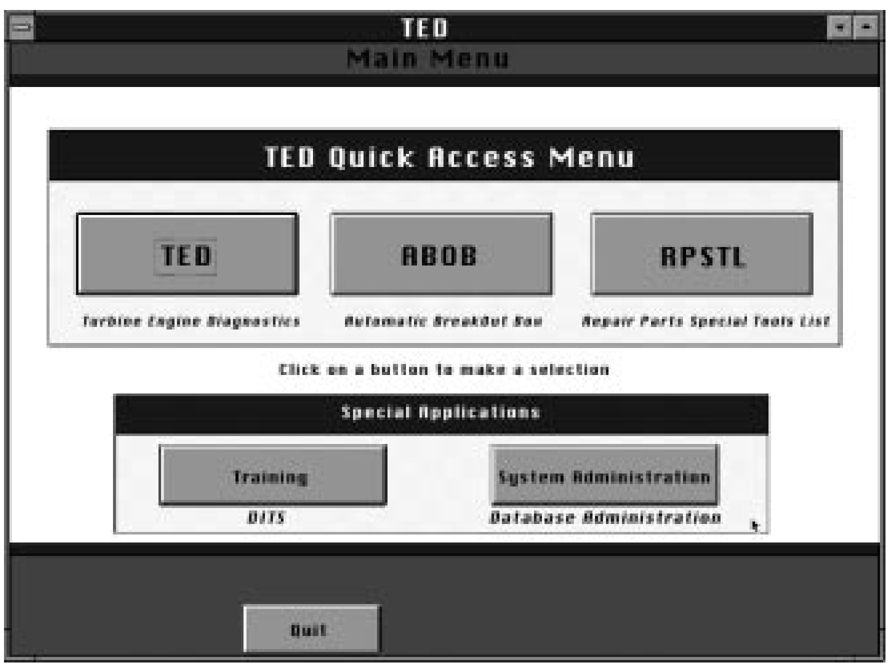


Figure 1. TED Main Menu

ABOB automates many of the diagnostic tests performed by the Simplified Test Equipment (STE). The STE was fielded in 1981 and is based on analog technology. Kregel is currently working on an advanced version of ABOB to automate STE functionality and reduce the number of manual tasks associated with STE.

Just as the 7-foot stack of paper manuals for the engine has been replaced by a single CD, ARL is extending the capabilities of the ABOB hardware and software to replace the set of seven huge trunks that house the STE.

Third Main Module—Repair Parts and Special Tools List (RPSTL)

The third main module of TED is the RPSTL module. This module greatly enhances the mechanic's ability to interrogate the parts ordering information for every aspect of the Abrams engine and transmission. The mechanic is provided the ability to search for items of interest in a variety of ways. In addition to being automatically linked from a diagnostic procedure, the mechanic can peruse the system from a general table of contents or choose to search for a specific part number, national stock number, or nomenclature.

Commenting on the importance of the RPSTL, one soldier put it this way: "Hey, I don't just find faults; I do more than that. And you're going to give me a computer that does this? Well, it isn't any good if I've still got to look it up in the tech manuals." Based on repetitive comments like this one, the team realized the importance of this reference tool. Said Helfman, "They [soldiers] wanted and needed it, so we threw in the RPSTL."

Figure 2 is a typical ordering selection form as it appears on the TED software. Its associated parts list is displayed on the right side, while its drawing is detailed on the left. Items are selected from the parts list by buttoning the particular order box. When necessary, portions of a drawing may be magnified to highlight areas of interest. Information from the RPSTL is automatically associated with its corresponding work order.

TED System Administration

The report writing and database maintenance functions enable the mechanic to automatically fill out and print DA Form 2404, Technical Inspection Form. In addition, TED provides numerous work order and statistical summaries. TED also permits online database maintenance procedures to insure that data integrity is maintained.

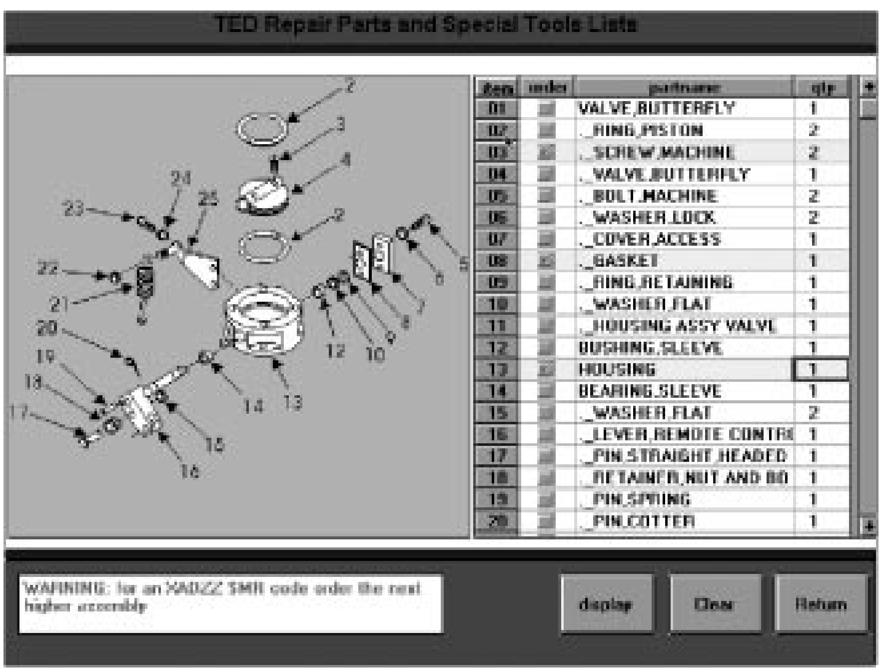


Figure 2. TED Repair Parts and Special Tools Lists

Diagnostic Intelligent Tutoring System (DITS)—A Diagnostic Trainer to Complement TED

The DITS module is a stand-alone embedded tutorial system that employs Intelligent Computer-Aided Instructional technology[4] to teach turbine engine diagnostics. DITS will determine the mechanic's level of expertise with troubleshooting procedures on the AGT-1500 Turbine Engine, level of troubleshooting experience and related knowledge, and preferred way of learning information. An adaptive program, DITS is designed to continually change its approach to presenting information as the mechanics begin to hone their diagnostic skills. It provides turbine engine mechanics with an automated capability to hone their diagnostic skills in both a field and garrison environment.

The DITS system consists of three separate modules: an introduction module, an AGT-1500 review module, and a diagnostics practice module. Besides a basic review in turbine engine maintenance procedures, DITS also provides the theory of turbine engine operations, and guidance on such tasks as hooking up the GHSS, using a digital multimeter, and accessing an online *Windows* tutorial. The DITS student aid section contains a notepad (for student notes), a glossary of frequently used terms, and a bookmark feature.

In addition, DITS is designed to be personalized, and each mechanic's session is keyed to a first-name entry system. DITS will automatically file and categorize each session by the mechanic's first name–and remind that same mechanic, once logged on the system, of the last session. Serving as both a diagnostic trainer and a diagnostic tool, DITS complements TED by providing mechanics a complete system.

Lessons Learned

Of the major lessons learned on the TED program, perhaps the one that

Forerunners of Acquisition Reform?

Several years ago, country western singer Barbara Mandrell popularized a song called "I Was Country When Country Wasn't Cool." In much the same way, that analogy describes the TED team, who were practicing key strategies of acquisition reform before they were institutionalized as the DoD's preferred way of doing business: Integrated Product Teams (IPT) and Advanced Concept Technology Demonstrations(ACTD). From the start, teamwork and cooperation were paramount. Concentrating on building an executable strategy, the team purposely identified and resolved issues as they arose. Focusing on cost control, they kept documentation to the necessary minimum; reported through the chain of command, as necessary; streamlined the decision process; and, where possible, reduced infrastructure. In a nutshell, they practiced the main tenets of IPTs: decide, promulgate, train, communicate, and implement.

Likewise, the team actively engaged in ACTDs during the entire life of the project. The user, at the start of a project, can rarely envision how technology can improve his or her job. A system based on initial user expectations will at best be shallow and may even be useless. The TED team adopted a soldier-centric paradigm that emphasized *support* rather than *supplant* as the end product. This method of open communication better enabled the team to leverage the experience of the SMEs while ensuring continuous soldier feedback during the incremental development. As a result, early prototypes gained quick acceptance and greatly added to the momentum of the program.

In the early years of the project, TED software modules were tested weekly using students in the Army Ordnance Center and School (OC&S). After the first formal test in August 1993, the need for testing was relaxed and is now done once a month using students from the OC&S. Additional user feedback is also provided monthly from the National Guard units that have received TED.

According to Dr. Richard Helfman, TED lead scientist and programmer, "Feedback from users may lead to small easy changes to the system, or may even lead to new system features or new software modules."

stands out, according to the project director and program manager, is the realization that software-intensive programs require an incremental management approach whereby successive prototypes are developed that refine user requirements and integrate emerging technology. The corollary to this is the realization that the user must be the foremost member of the development team. In addition, the TED team realized that an integrated product team approach produced the best results (see Forerunners of Acquisition Reform, left column).

Find the Right Life-Cycle Model for Your Program. The traditional software life-cycle management model, also referred to as the waterfall method, emphasizes a systematic approach of dividing software development into exact stages. Each subsequent stage is predicated upon completion of the previous stage, hence the reference to a waterfall. However, this paradigm is not conducive to rapidly changing user requirements and the rapid rise of technology improvements.

TED development required an incremental life-cycle management system that enabled the team to rapidly develop prototypes consisting of individual modules that could be used separately or in conjunction with the parent program, test their applicability, and integrate their functionality. The traditional waterfall software development model did not allow for this flexibility. Hence, the team determined that a more responsive development paradigm had to be used in order to promote incremental development through the use of rapid prototyping. After searching for an answer, the team decided to employ the Rand Expert System Life Cycle Process Model.

Rand's *Management of Expert Systems Development Guide*[5] advocates a risk-driven approach to expert system development that enhances the likelihood of success through early recognition of potential problem areas in program cost, schedule, and performance. The Rand development paradigm consists of six separate and distinct phases: Initiation (Milestone 0), Concept (Milestone I), Definition/Design (Milestone II), Development (Milestone III), Deployment (Milestone IV) and Post-Deployment. Each phase is roughly equivalent to the classic Life Cycle System Management Model. However, the basic difference is that each phase of the Rand paradigm produces a distinctive prototype that serves as the de facto exit criteria to move from that particular phase to the next. The prototypes are continually refined throughout the Rand Expert System Life Cycle based upon the results of continual user testing as well as the insertion of emerging technological innovations.

Referring to user reaction, Illi commented, "Rick [Helfman] and I decided to employ the Rand Model... because it allowed us the flexibility to use a series of successive prototypes to explore user reaction and incrementally improve system functionality. In essence, it allowed us to determine that if a prototype works, then we can build on it. If it doesn't work, then we stop, go back, and rebuild that specific prototype."

As was mentioned at the onset of this article, an operational prototype version (Version 1.3) of TED is currently being tested at 65 Army National Guard Regional Maintenance Sites across the United States. The National Guard provided the TED team with an opportunity to continually evaluate TED performance in an operational environment. Based on these field evaluations, the TED team routinely tests new modules and incorporates recommended changes, based upon input from these extended field tests.

Soldier-centric. This phrase was initially coined by Timothy Hanratty and refers to yet another major lesson learned. Actually, it may be more appropriately labeled a sound, joint programmatic decision made by both Helfman and Illi at the onset of the program—a decision that proved its worth many times over.

Actively involving the soldier—the ultimate end user—in TED's development from the start proved to be the life blood of the program. According to Helfman, "I strongly believe that if you want to build something that a soldier will use, you must live with the soldier from the first day of the process."

Programmers and SMEs do not speak the same language. Programmers talk of frames, objects, and Source Lines of Code (SLOC). M1 mechanics talk of Inlet Guide Vane angles, and of Rotational Variable Differential Transformers. Each needs to learn some of the other's language, but TED's main effort was to have the programmer learn the language of the mechanic.

The team decided the best way to do this is to observe the user in his or her environment. As a starting point, they attended and videotaped classes for M1 mechanics. This produced three important benefits.

- First, it quickly immersed the programmers into the language of the mechanic. The Inlet Guide Vane is right in front of the engine, and the angle determines how much air gets through to the turbine blades.
- Second, it gave an accurate picture of how a mechanic performs his or her job, and how software might improve that job. The TED team noticed during the first session that the original scope of work was too narrow. There was a whole suite of software that could help the mechanic better perform his or her job.
- Third, it established a bond between programmer and soldier. Soldiers could sense that the team was serious and that soldier's needs would be given serious attention. They were thus eager to cooperate.

When the aim is to produce software that not only works as planned, but also gets used by the mechanic, then user participation in the development

According to Helfman, "I strongly believe that if you want to build something that a soldier will use, you must live with the soldier from the first day of the process."

process is critical. The TED team heard many stories from soldiers about equipment that never gets used and about equipment that is difficult to use, for which a small change would have made the item soldier-friendly. The TED SMEs were assigned full time to the project.

Helfman readily admits that when the team started the program, they pretty much thought they could do it themselves. "We're programmers, so that's what we're good at. And the Ordnance School basically fixes tanks; that's what they're good at. We quickly learned that if we work together, it really works great...That's when we organized into a cohesive and cooperative team...We knew that it was so inherently difficult to do that nobody could do it alone."

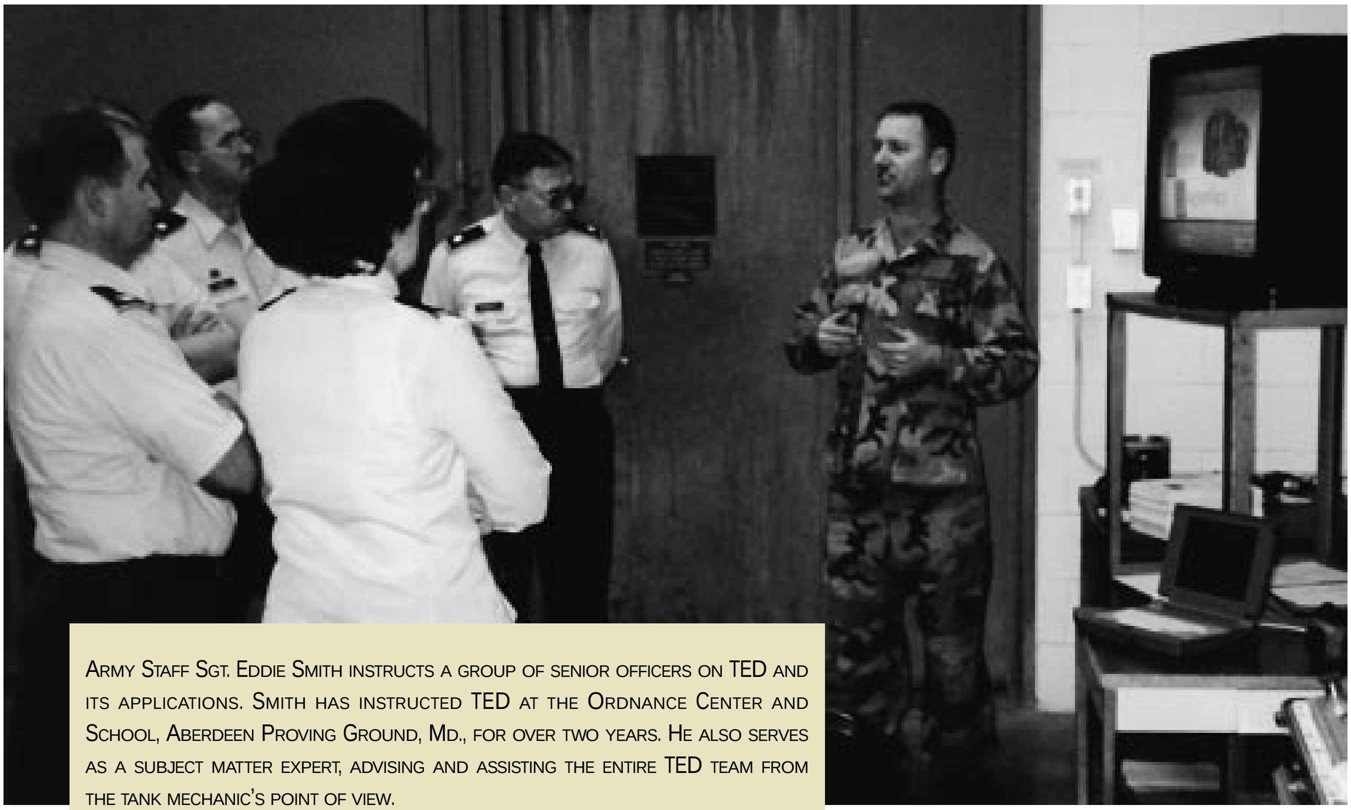
Illi affirmed his assessment, stating that "It was a sobering experience for all sides. For ARL, because they knew they couldn't do it without the soldiers. For the soldiers, they knew they couldn't do it without ARL. For me, charged with trying to pull this whole thing together because we knew that we *all were going to sink or swim together*—that no one group was more important then the other."

Holly Ingham, who is currently working on the TED program as a computer scientist, also spoke of the importance of not trying to go it alone. "This field of artificial intelligence is growing by leaps and bounds. I think back in '91 it was probably breaking a lot of new ground. I'm currently taking an artificial intelligence class now in graduate school and they're telling me, 'You can't develop an expert system without a marriage between the expert and the programmer.' And the TED team learned that early on. Now it's coming out in school—yes, that's the only common sense way to make an expert system."

John Dumer, a computer scientist and TED programmer, also described the team's soldier-centric strategy as the most common-sense approach. "You're marrying programmers with subject matter experts, and you're finding that least common denominator, which was the soldier, that we wanted to develop this software for. And if you keep the soldier in mind the whole time—is this good for the soldier—it all made sense."

Risktaking. Perhaps the most painful lesson learned by Illi and the team involved risktaking. "You have to be willing to take hits," said Illi, "and do total revamps of the software when you find out that you're going in the wrong direction. Hopefully, you catch it early on. But if you don't, you still have to be willing to take the hit, go back, and do it right."

Citing a specific example, Illi talked about the early days of the project. "One of the things I learned the hard way, is that you have to be able to accept that you're going to fail. Because four months into the project we had to completely change our primary expert system authoring software...We had to abandon a rule-based



Army Staff Sgt. Eddie Smith instructs a group of senior officers on TED and its applications. Smith has instructed TED at the Ordnance Center and School, Aberdeen Proving Ground, Md., for over two years. He also serves as a subject matter expert, advising and assisting the entire TED team from the tank mechanic's point of view.

system that we learned very early on simply wasn't going to work." As program manager, it fell to Illi, to consider the ramifications of whether to continue the program with the original authoring software, knowing that it had a high probability of failure; or to take the hit now, and rework the concept prototype–a decision that would result in a six-month program delay. Given the importance of the project, he advised his superiors to take the hit now and rework the concept prototype. Both Illi and the program survived–a tribute to the Ordnance School leadership who were tolerant of failure in the face of reasoned risktaking.

Speaking of risktaking in an acquisition culture that was, by its very nature, inevitably risk-aversive, Illi said that "We took a lot of risks; the field of Artificial Intelligence is a risk-laden arena. There is a lot of theory on how to develop an operational expert system, but very few examples of how to get there. So if you looked at it from the standpoint of whether or not all the risks were warranted, I can only conclude that, yes, at the time they were."

Both Helfman and Illi spoke of how the team, when it was determined that the original software choice was clearly not going to work, evaluated a newly formed company that was literally unknown by anyone outside of the artificial intelligence community. Because the team liked and respected their product, they flew to Washington state and visited this small company on-site. Helfman remembers, "We convinced ourselves that these guys were going to be in business for the length that we needed them to complete the project, so we said, 'You know, we like your product; we think it's great.' But we wanted some features that they didn't have. So we asked, 'How much will it cost to add these features?' When they told us about $50,000, we said, 'When can we have it?' You know, we were getting delivery of the product within a matter of months."

"That," Illi continued, "was probably the greatest single risk that we took, because the program was dead in the water; I had to make a call, based upon an 80-percent solution set. The main program management lesson that I learned is that you are never going to have all the data you need to make a decision. The program manager has to be willing to take the risk. *If you're going to stay in a comfort zone, then you're not going to field the system.*"

The new software, *Visual Expert*, by SOFTSELL™, provided a significant improvement over the existing authoring system, was user-friendly in that the frame-based reasoning actually replicated the way the team's head SME, Army Master Sgt. Ralph Ishman, actually diagnosed problems. He literally sat down at the computer and gave the team his ideas on the way the logic flow should work–not based upon the current TMs, but based upon his heuristics or rules of thumb, developed through years of operational experience. These heuristics, were the backbone of TED. *Visual Expert* allowed Ishman to capture them in a concise manner.

Ishman, now retired and working for a private trucking firm, reflected on his tenure working as the primary SME for TED from 1991 through 1996: "TED was a tool for the soldiers. It was a matter of bringing the soldier who did not have access to computerized equipment, into the information age. My main objective was to fit the software to the soldier in the field, like me, who had never used a computer. As a mechanic, I wanted to see the programmers build the computer program for the soldiers, not the scientists. I wanted it to include 'real life' applications and be a tool for them to use just as they would any tech manual or tool—not just a computer screen. And it worked. Many of the soldiers using it for the first time actually did not realize they were using a computer." Ishman, even in retirement, remains an invaluable member of the team, such that he still gets calls from time to time, asking for his opinions or assessments.

As an aside, the U.S. Naval Post Graduate School has employed the same software—based upon recommendations from the TED team—to construct an expert system for diagnostics on the Mark 92 radar.

Leveraging Commercial Off-the-Shelf (COTS) Software

Another important lesson learned, according to Helfman, was the fact that "You can't do a big project in one package...you may need up to a dozen different software packages." Early into the TED project, the team decided that time was better spent on knowledge acquisition and testing than on pure code development. As a result, COTS software was leveraged whenever and wherever applicable. COTS products provided the high quality, lower cost, and added flexibility the project required. The TED team capitalized on the COTS products of *Visual Expert*, *Visual Basic*, *Access*, *Toolbook*, and *HyperWriter*. In-house code was developed using Microsoft C++ and Borland's Delphi languages.

Adoption of the COTS approach complemented the team's rapid prototyping life cycle and soldier-centric beliefs. Solutions to hardware and software problems were changed or altered component by component without adversely affecting the whole. In the early years of the project, the team tested the software at least weekly, using students in the Ordnance School. Feedback from the users led to changes, ranging from small modifications to the addition of new system features. With COTS, the ability to identify and rapidly install emerging technologies was made easier. After the first formal test in August 1993, the need for testing was relaxed and is now done once a month. Primary feedback now comes from the Ordnance School and National Guard units that have received TED.

Noting that you can't have the good with the bad, Helfman reminds us there is a downside to COTS that must be remembered: "Each package has its own features, but they all must work together. That's usually where the problems surface: packages communicating with packages." Purchasing COTS products has to be approached with caution. Careful consideration must be given to correctly match system requirements to the potential COTS product's model. Not only does the COTS product have to adequately match the functional requirements of your environment, it must match the operational requirements as well. Incorrect matching can lead to expensive change orders that eliminate any potential cost and time savings. Additionally, legal distribution and software copyrights need to be weighed when dealing with COTS products. A product purchased without unlimited distribution rights can prove quite prohibitive. Today, the team continues to track the latest software and hardware trends, actively looking for yet other system improvements.

What Do We Gain?

Subsequent to the fielding of the Operational Prototype to the National Guard, a trend toward maintenance cost savings began to emerge. According to Helfman, "Essentially, rather than randomly replacing parts on the engine until it starts working again, which was the old way, the system walked the soldier through a more methodical approach, a higher percentage of hitting the defective part the first time."

The goal of the TED program is to save money by reducing the diagnostic error rate. An 80-percent error reduction will save roughly $8 million each year by avoiding unneeded repair. The TED program is on its way to achieving this goal.

- In 1993, the University of Delaware conducted a formal user test using 30 soldiers from the Tennessee National Guard. The results showed that TED cut the error rate by 50 percent.
- In the summer of 1994, units from two different state National Guards received early versions of the TED software. Each state had three broken engines slated for turn-in. Each state had diagnosed the bad engines before TED arrived. On Saturday, July 9, TED was used on the three engines from one state, and on Sunday, July 10, on the three engines from the other state. Of all six engines, the pre-TED diagnosis was wrong, and the TED diagnosis was right. Thus, in the first two days of fielding, TED saved the Guard six incorrect engine repairs at a cost savings of over $50K.
- By summer of 1996, ABOB diagnostics had error rates well below 5 percent.

Training/Proficiency. Successful development and fielding of TED will increase the effectiveness of ordnance soldiers. TED, by virtue of its modular design and its embedded tutorial program, preserves and encodes mechanics' rules-of-thumb or heuristics that are employed routinely in daily maintenance operations, but are lost when personnel are transferred or leave the service. Once these hueristics are incorporated in TED, they are codified and can be passed on to novice and apprentice mechanics, thus improving their training and daily proficiency.

TED Team Wins Award

TED Team Wins ADPA Logistics Artificial Intelligence Applications Award

On March 9, 1993, retired Maj. Gen. William E. Eicher, Vice President, American Defense Preparedness Association, presented ADPA's Logistics Artificial Intelligence Applications Award for 1993 to Army Lt. Col. Orlando J. Illi, Jr., and the members of the original TED team: Drs. Richard Helfman and Mark Kregel; John Dumer; Capts. Janet Palfrey, Sherman Charles, and Mark Malham; Chief Warrant Officer Charles Ortt, Sr.; and Army Master Sgt. Ralph Ishman.

In 1994, the TED team, with the addition of representation from Pacific Northwest National Labs (PNNL), was again nominated for the same award for their pioneering work in the field of Prognostics. The nominated program—TEDANN (Turbine Engine Diagnostic Artificial Neural Net)—is currently undergoing advanced development at PNNL under the sponsorship of the U.S. Army Logistics Integration Agency and the U.S. Army Artificial Intelligence Center. The renomination was highly unusual in that the same team was nominated for the same award, two successive years.

In addition, TED routinely provides both the user and mechanic with real-time system assessments. This capability will necessarily reduce Preventive Maintenance and Checks System requirements as systems are designed to monitor their own performance parameters.

Soldiers consistently prefer TED to attain training and proficiency. "We've had folks tell us that they like to come to work when they can use TED," said Helfman. "You know, that certainly was never part of our scope, but they tell us 'Hey, if I come in and I get to work on an engine and get to use TED, that's a happy day. If I have to go and work on something else and use the manuals, it's not a happy day.' So it's had a secondary effect of enhancing morale, which I think if you could quantify it, is very important."

The Ordnance School places such confidence in TED that they have published a TED User Manual and are teaching TED to their basic and advanced NCO courses as well as their maintenance warrant officer courses.

What's Ahead?

The first obvious extension to the TED project involves the creation of a TED associate. Identified as a possible candidate to capitalize on TED's model of maintenance is the U.S. Army's Bradley Fighting Vehicle (BFV). Similar to the Abrams MBT, the BFV has its own special maintenance issues. Toward this end, the National Guard Bureau has shown increasingly strong interest and continues its pursuit.

A second possible direction for consideration includes extending the TED project into the turret systems of the Abrams tank. Strong arguments have been made that ABOB technology would improve the efficiency and effectiveness of turret diagnostics.

Still a third logical extension of TED is the premise that expert diagnostic systems can be developed to predict when a part will fail. This concept, referred to as prognostics, was first envisioned by Illi in 1993. At that time, he assembled a team consisting of representatives from Pacific Northwest National Laboratories, ARL, and the Ordnance School to explore this concept. The program, referred to as TEDANN (Turbine Engine Diagnostic Artificial Neural Net), successfully demonstrated that a neural net could be constructed to perform prognostics on a turbine engine. The technology inherent in TEDANN was judged to be of sufficient merit to be nominated for the 1994 ADPA Logistics Artificial Intelligence Award. After Illi's retirement, the TEDANN project was continued by Army Lt. Col Steve Barth, at the U.S. Army Logistics Integration Agency (LIA). Barth gives us this update on the TEDANN program.

ORIGINAL TED TEAM AS THEY RECEIVED THE 1993 ADPA LOGISTICS ARTIFICIAL INTELLIGENCE APPLICATIONS AWARD.

Photo courtesy Dr. Richard Helfman

"The Logistics Integration Agency is pursuing the development of an operational prototype of the TEDANN as a proof of principle for Army-wide application across a wide spectrum of vehicle platforms. The potential of an artificial intelligence application like neural nets provides the field commander with a reliable predictive maintenance capability to forecast "down time." TED was selected as the developmental candidate because of its mature nature as an Interactive Electronic Technical Manual (IETM).

Presently, TED is used by mechanics after failure of the AGT-1500 engine to diagnose the repairs needed to return it to operational readiness. By hooking in through a databus connection on the engine, TED functions as a "tool" for the mechanic by troubleshooting the associated sub-systems of the engine and isolating the faults through sensors embedded in the engine. This diagnostic capability is a tremendous aid in identifying faults; unfortunately, diagnosis occurs after a failure. Often this failure is catastrophic, but always inconvenient.

TEDANN will (1) monitor the same sensors while in operation; (2) "learn" from previous failures (by tracking the patterns that led to failure); and (3) predict the time and likelihood of the next failure. Applied across the spectrum of weapons platforms and used with IETMs found in a task force, artificial neural nets could predict the availability of systems for the next fight or the duration of a task force deployment.

In pursuit of TEDANN, LIA is currently negotiating the site for the TEDANN development of the baseline of sensor readings to begin to build the "learning" database. Under consideration for test vehicles are M1A1s within the Washington or Oregon National Guard, test vehicles at Yuma Proving Grounds, and M1Als within the rotational fleets supporting the National Training Center at Fort Irwin, Calif. Selection of the fleet and the concept supporting the collection of the sensor readings will not be finalized until approval by LIA and PM M1A1."

Bottom Line—Soldier Acceptance

The entire TED team is excited about the degree of soldier acceptance since onset of the program. Said Helfman, "The Marine Corps and virtually everyone that comes here [ARL], everyone that sees it, is excited about it. Most want the system right away. They are going to get it, but it's a few years downstream." The team is constantly surprised when they travel, that soldiers not only know about TED before they get there, but are more than anxious to get it. Soldier acceptance, however, is portrayed best by the TED project director's measure of success:

"My measure of effectiveness is the smiles we see on the soldiers' faces."

—Dr. Rick Helfman

Editor's Note: As part of my research for this article, I attended a TED Demo, which was given by Army Staff Sgt. Eddie Smith to a group of basic noncommissioned officer students (E-5) at the Army Ordnance Center and School. The class had heard of TED, but had never seen the TED software in action. Helfman's measure of success is accurate—I saw the smiles and looks of amazement on the soldiers' faces; they were eager to ask questions, and eager to test it out. If soldiers' reactions are any sort of gauge, it looks as though the Army has itself a winner.

About the team: The team members are Baur, Dumer, Hanratty, Helfman, and Ingham. They are assigned to the Intelligent Systems and Technology (IS&T) Directorate, ARL, as computer scientists and TED programmers. Dumer, Hanratty, and Helfman are part of the original TED development team. Baur and Ingham joined midway. Helfman was the original lead scientist on the TED program. He is currently TED project director. Smith is a noncommissioned officer and TED instructor, assigned to the Ordnance School. He also serves as the TED subject matter expert, advising the team from the soldier's point of view. Kregel is a retired ARL scientist who designed and built the ABOB. He is under contract to the ARL to expand the ABOB's capabilities. Illi is a retired Army lieutenant colonel, and original project manager for development of the Turbine Engine Diagnostics system or TED. Prior to his retirement, he served as the Director of Automation at the Defense Systems Management College. He is currently employed by Systems Research and Applications International, Inc., as a senior member of their professional staff, responsible for managing the Medical Advanced Technology Management Office Knowledge Engineering Group, at the U.S. Army Medical Research and Development Command, Fort Detrick, Md.

For further information Helfman suggests users access TED's Home Page on the Internet:

http://www.arl.mil/ARL-Directorates/ASHPC/SISD/ted.html

He also encourages users to send him an E-mail with any comments, suggestions, or questions:

helfman@arl.army.mil

References

1. Georgeff, Michael P. and Amy L. Lansky, "Procedural Expert Systems," Proceedings of the Eighth International Joint Conference on Artificial Intelligence, Karlsruhe, Germany, 1983.
2. Georgeff, Michael P. and Amy L. Lansky, "A System of Reasoning in Dynamic Domains: Fault Diagnosis on the Space Shuttle," Technical Note 375, SRI International, 1986.
3 Advanced Decision Systems, "Procedural Reasoning System," Working Paper, TR-ADS-0015, October 1988.
4. *Intelligent Tutoring Systems*, Sleeman and Brown (ed), Academic Press, Inc, 1982, p. 1.
5. *Guide for the Management of Expert Systems Development*, R-3766-P&L, Rand Corporation, July 1989.